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AFFDL ltr, 28 Nov 1979

AFFDL-TR-74-43

AD 923477

A FRICTION IGNITION MECHANISM FOR A SODIUM CHLORATE CANDLE

Edward B. Thompson, Jr.

TECHNICAL REPORT AFFDL-TR-74-43

September 1974

Air Force Flight Dynamics Laboratory
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

AFFDL-TR-74-

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The technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFFDL-TR-74-43	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* A FRICTION IGNITION MECHANISM FOR A SODIUM CHLORATE CANDLE		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edward B. Thompson, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Flight Dynamics Laboratory Wright-Patterson Air Force Base, Ohio		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 6146
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE September 1974 13. NUMBER OF PAGES 25
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Sodium Chlorate Candles
Oxygen Generation
Atmosphere Control
Ignition Mechanism
Emergency Oxygen

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This report concerns an in-house investigation through which a highly reliable/low heat release method of chlorate candle ignition was developed. The program proceeded on the basis of the two problems most frequently encountered in chlorate ignition, namely, failure of the candle igniter itself to function (or to activate the candle if it does operate) and the high heat release in standard candle ignition which can cause a housing burn-through.

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The program approach consisted of formulating a variety of combustible mixtures, each one applied to a chlorate candle specimen and tested for friction ignitability.

Sixty different mixtures were formulated and tested of which five proved satisfactory. These five exclusively contained sodium chlorate, iron powder, maganese dioxide, potassium permanganate and potassium nitrate.

FOREWORD

This technical report was prepared by the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This effort was documented under Project No. 6146, Task No. 6146 01, Work Unit 6146 01 08 in the Environmental Control Branch (Advanced Oxygen Systems Group) of the Air Force Flight Dynamics Laboratory. Mr. Edward B. Thompson, Jr. was the principal investigator.

The subject report summarizes an in-house program concerning the formulation, development, and test of a combustible material to be used for friction ignition of a sodium chlorate candle not having a fuel-rich cone. The candidate combustible materials were tested for comparative ignitability on a standard sodium chlorate candle formulation.

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SECTION I

INTRODUCTION

A major problem experienced by many investigators in chlorate candle technology has been the "burn-through" of the candle housing. Figure 1 depicts the probable location of burn-throughs as they have occurred under laboratory and field conditions. Note the proximity of the burn-through to the cone. Since molten cone temperatures range from 1850°F to 2400°F, any direct contact between the melt and a thin-wall steel housing will most probably result in a burn-through. The mechanism of the burn-through might be described as follows: immediately upon ignition of the primer, the cone and surrounding candle fracture due to the ignition shock; the molten cone then spurts against the housing inner wall. If the candle is in a horizontal position when activated, the molten cone spills out of the candle onto the housing inner wall. In either case, the melting point of the stainless steel housing is near the temperature of the molten cone material, and this material can then readily cut through the steel shell.

The conventional approaches to preventing the housing burn-through have consisted of mechanical or quick-fix types of corrections, such as capping the cone with a splatter cup (Figure 1). A ceramic liner can also be installed between the candle and the housing wall (Figure 2). Another approach is to recess the cone (Figure 3), a less expensive technique than the former, albeit a difficult step in the manufacture of the candle. Recessing the cone usually prevents the melt from the cone cavity from spilling onto the housing wall, but it could increase the chances of the candle fracturing on "ignition impact," with the molten cone then spilling through the cracks onto the housing wall.

The cone can introduce another problem. If the cone is too large and/or burns at too slow a rate, the candle will melt instead of igniting, which has resulted in many candle failures. A high heat release over a small area of candle material (i.e., high heat concentration) is necessary for candle ignition. The cone or quantity of

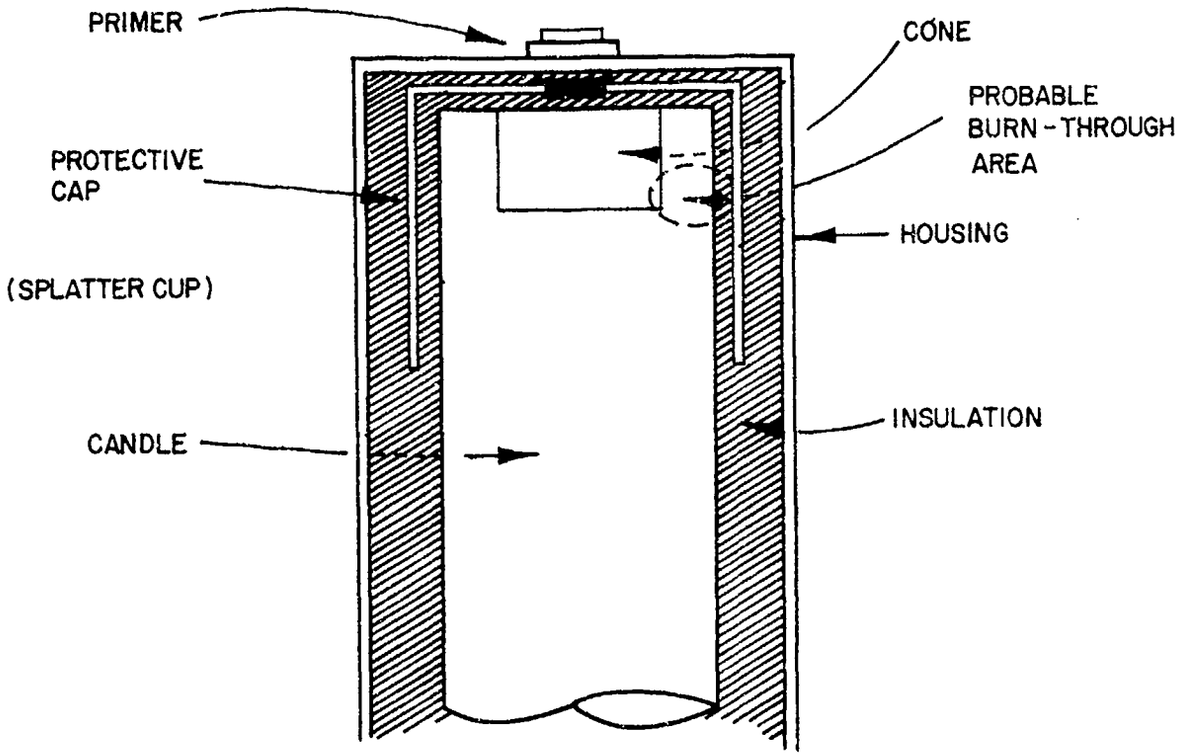

Figure 1. Cone with Splatter Cup

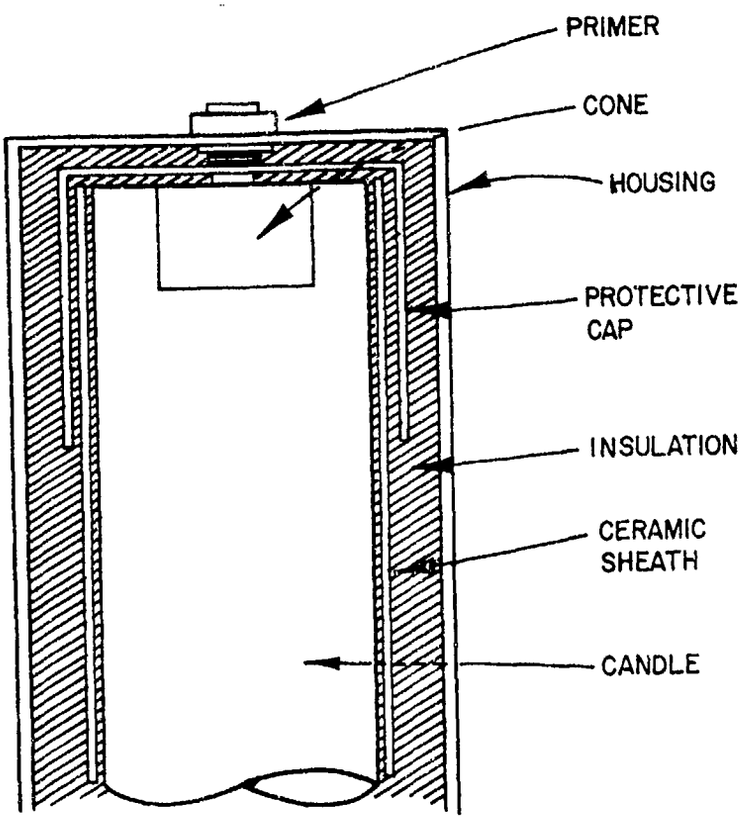

Figure 2. Candle with Ceramic Sheath

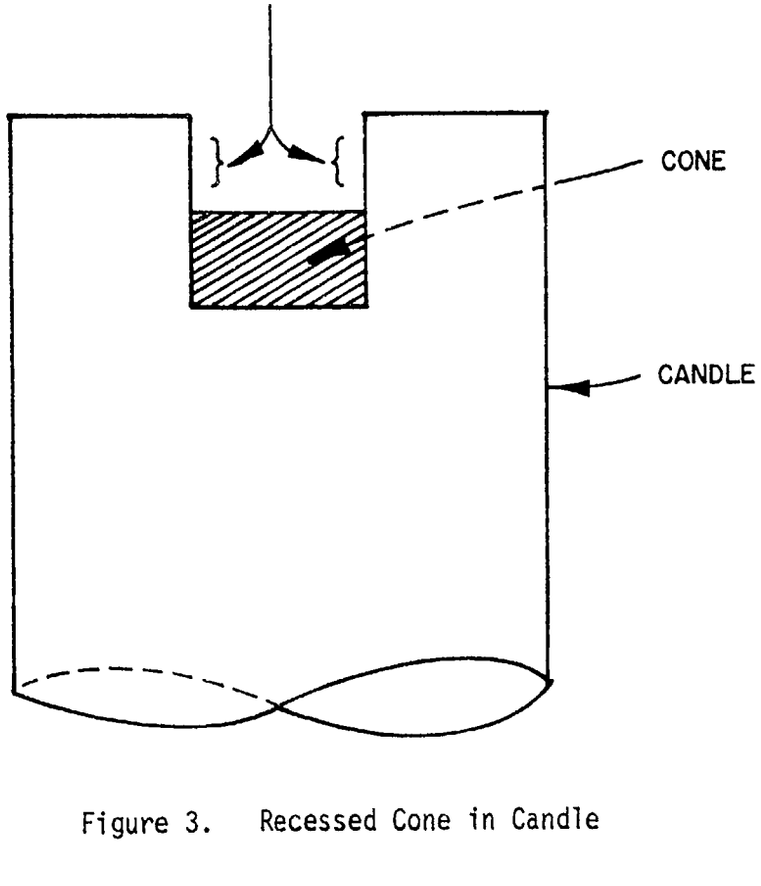

Figure 3. Recessed Cone in Candle

cone material should be sized in proportion to the candle surrounding it, a proportion determined largely through practice. The formulation of the cone must also contain sufficient iron (usually 20 to 35%) to liberate sufficient heat for ignition.

These problems associated with cone/candle ignition led the investigator to consider an alternative to using a cone for ignition. A first approach might be to use a candle which could be ignited directly from a primer or squib. The candle at the ignitor end would contain enough fuel so that the entire ignition end of the candle would, in effect, be a cone. This design, unfortunately, produced the same problem as was discussed before - too much heat was liberated, resulting in a burn-through. If the cone could consist of only a thin combustible layer applied to the end of the candle, however, the candle might be ignited without burn-through. This layer of material would catalytically ignite the candle without producing high heat. The material would be activated by a simple friction device, which would abrade the surface to start combustion. This mechanism seems to have sufficient promise to merit a thorough investigation.

SECTION II

SELECTION OF CANDIDATE MATERIALS

Manuals on pyrotechnics and flash powders provided a reference background for selecting the ingredients to be formulated and tested. The following components (formula in parentheses) were then selected for compounding and testing:

Sodium Chlorate ($NaClO_3$)	Iron Powder (Fe)
Aluminum Powder (Al)	Silicon Powder (Si)
Iron Oxide (Fe_3O_4)	Carbon (C)
Potassium Nitrate (KNO_3)	Silicon Dioxide (SiO_2)
Potassium Permanganate ($KMnO_4$)	Manganese Dioxide (MnO_2)
Sodium Silicate ($Na_2 SiO_3$)	Sodium Chloride (NaCl)
Glycerine ($CHOH(CH_2OH)_2$)	Copper Powder (Cu)
Fiberglass (Pyrex)	Manganese Powder (Mn)

The above ingredients were then formulated into the combinations depicted in Table I.

Sodium chlorate was included as a component in each first-fire formulation to "prime" the ignition of the sodium chlorate candle specimen. The other components were intended as fuels, burning rate additives, or heat-holding compounds. Table I specifies the exact percentage of components in each first-fire formulation.

The glycerine and sodium silicate were intended to serve as vehicles for preparing the material paste. After compounding each dry formula, the vehicle was added in sufficient quantity to make a moist slurry. The slurry was then applied to the end of a specimen size candle with a spatula and oven dried at 225°F. Figure 4 illustrates a typical finished candle.

TABLE I. Selected First-Fire Formulations

PERCENT COMPONENTS BY WEIGHT																
FORMULA NUMBER	$NaClO_4$	Al	Fe_3O_4	KNO_3	$KMnO_4$	Fe	Si	C	SiO_2	MnO_2	NaCl	Cu	Mn	Binder		Fiberglass Particles
														Na_2SiO_3	Glycerine	
1	75	4	-	2	3	4	-	-	1	3	2	3	3	X		X
2	75	3	1	3	1	4	-	1	1	3	2	3	3	X		X
3	75	2	-	2	4	4	3	-	2	4	2	-	2	X		X
4	80	4	1	2	-	2	1	-	-	3	1	3	3	X		X
5	80	3	1	2	1	2	1	-	1	4	1	2	2	X		X
6	80	2	1	2	2	3	2	1	-	2	-	2	3	X		X
7	80	1	2	2	3	4	3	-	-	3	-	1	1	X		X
8	75	-	-	5	5	5	-	-	1	5	2	2	-	X		X
9	85	5	-	2	3	2	-	-	-	1	1	1	-	X		X
10	85	-	5	2	3	2	-	-	-	1	1	1	-		X	X
11	75	-	5	5	5	1	1	1	2	2	1	1	1		X	X
12	75	-	5	-	5	3	2	-	2	2	2	2	2		X	X
13	80	5	2	1	2	1	-	-	-	2	3	2	2		X	-
14	80	5	2	1	3	-	1	-	2	1	2	2	1		X	-
15	80	5	2	1	4	1	1	-	-	2	1	1	2		X	-
16	90	1	1	-	1	1	1	1	-	1	1	1	1		X	X
17	90	1	1	1	1	1	1	-	-	1	1	1	1	X		X
18	85	2	2	2	2	1	1	-	-	2	1	1	1	X		X
19	85	1	2	-	-	-	-	-	-	-	-	-	-	X		X
20	85	1	1	2	2	2	1	1	-	1	2	1	1	X		-
21	85	1	1	1	1	2	1	-	2	2	-	2	2	X		-

TABLE I (Cont'd)

PERCENT COMPONENTS BY WEIGHT																
FORMULA NUMBER	$NaClO_4$	Al	Fe_3O_4	KNO_3	$KMnO_4$	Fe	S	C	SiO_2	MnO_2	NaCl	Cu	Mn	Binder		Fiberglass Particles
														Na_2SiO_3	Glycerine	
22	80	2	1	1	3	2	1	-	3	2	1	2	2	X		X
23	90	2	1	1	1	1	-	-	-	1	1	1	1		X	X
24	90	2	1	-	1	2	-	-	1	1	-	1	1		X	-
25	85	2	2	1	1	1	2	-	1	1	2	1	1		X	X
26	85	2	1	1	2	2	-	-	1	2	-	2	2		X	X
27	90	1	1	1	1	1	1	-	-	1	1	1	1		X	X
28	90	1	-	2	2	2	-	-	-	2	1	-	-	X		X
29	85	2	2	1	-	3	-	-	-	3	2	-	2	X		X
30	85	-	2	1	3	2	1	1	1	1	1	1	1	X		X
31	85	2	3	1	4	1	-	-	-	1	1	1	1		X	X
32	85	3	2	2	3	-	1	1	-	2	-	-	1		X	X
33	85	5	-	3	2	5	-	-	-	-	-	-	-		X	X
34	85	4	1	4	1	2	1	-	-	2	-	-	-		X	X
35	85	-	5	5	1	2	-	-	-	2	-	-	-		X	X
36	85	-	4	4	2	1	-	-	-	1	1	1	1		X	X
37	85	-	3	3	3	-	-	1	1	1	1	1	1		X	X
38	85	-	2	2	4	2	1	1	1	1	1	-	-		X	X
39	85	-	1	1	5	2	2	-	-	3	-	1	-		X	X
40	85	-	1	2	3	3	1	-	-	2	1	1	1		X	X
41	85	-	-	3	2	4	1	-	-	3	-	1	1		X	X

TABLE I (Concluded)

PERCENT COMPONENTS BY WEIGHT																
FORMULA NUMBER	$NaClO_4$	Al	Fe_3O_4	KNO_3	$KMnO_4$	Fe	Si	C	SiO_2	MnO_2	NaCl	Cu	Mn	Binder		Fiberglass Particles
														Na_2SiO_3	Glycerine	
42	85	-	-	2	2	2	-	-	3	2	1	-	1		X	X
43	85	-	-	2	1	2	2	-	-	2	2	2	2		X	X
44	85	-	1	2	4	1	1	-	2	1	1	1	1		X	X
45	85	-	-	4	4	1	1	-	1	1	1	1	1		X	X
46	85	5	1	1	1	1	1	-	1	1	1	1	1		X	X
47	85	3	1	2	2	1	1	-	1	1	1	1	1		X	X
48	85	2	1	2	2	2	1	-	1	1	1	1	1		X	X
49	85	1	-	2	2	3	1	-	-	3	1	1	1		X	X
50	85	4	1	1	1	2	-	-	1	2	1	1	1		X	X
51	88	2	1	1	2	1	-	-	1	1	1	1	1		X	X
52	88	2	1	2	2	2	-	-	-	3	-	-	-		X	X
53	88	2	1	2	2	2	-	-	-	2	-	1	-		X	X
54	88	-	-	3	3	3	-	-	-	2	-	-	1		X	X
55	88	1	1	2	2	2	-	-	-	2	1	1	-		X	X
56	88	-	1	2	1	4	-	-	-	4	-	-	-		X	X
57	88	-	-	3	1	4	-	-	-	4	-	-	-		X	X
58	88	-	-	2	1	5	-	-	-	4	-	-	-		X	X
59	88	-	-	1	2	4	-	-	-	5	-	-	-		X	X
60	88	-	-	3	3	3	-	-	-	3	-	-	-		X	X

Some fiberglass particles were added to the sodium silicate and glycerine solutions so that a "mat" would form upon drying.

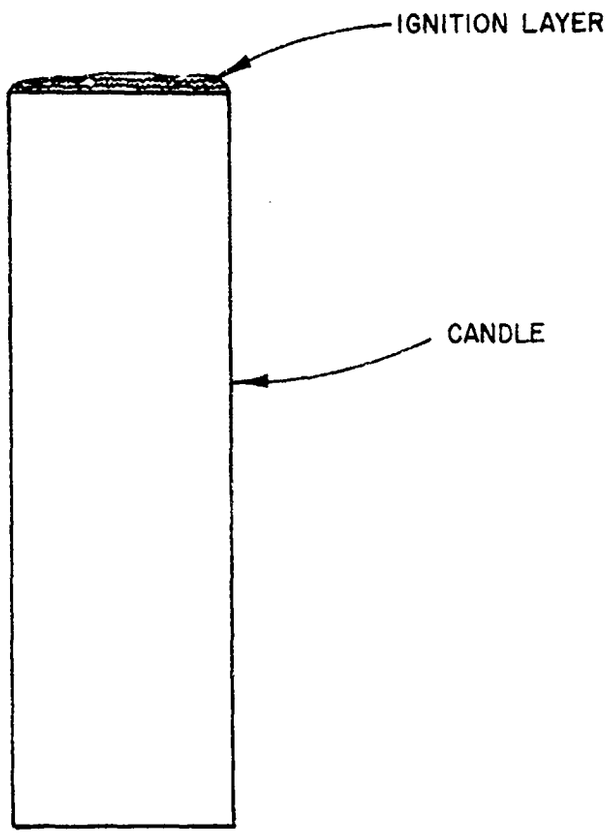

Figure 4. Candle with Friction Ignition Layer

SECTION III

TEST PROGRAM

The method of testing used in this program consisted of compounding the selected formulations specified in the previous section, followed by trial-and-error testing. The sole objective of the testing was to establish which formulations would ignite by friction (on a striking surface), and then be capable of igniting the candle specimen.

Figure 4 illustrates a candle specimen with material applied to one end. Each candle specimen measured 7/8 inch in diameter and 4 inches in length, and weighed 100 gms. Over 100 such specimens were prepared by the hot press method - a technique described in full detail in other reports (see References 1-4). The formulation of each candle specimen consisted of 88% sodium chlorate, 6% iron powder, 4% manganese dioxide, and 2% fiberglass particles.

The candle specimens were kept in dry storage and were withdrawn as needed for testing each formulation. Each test specimen was prepared by mixing the dry formula with either glycerine or sodium silicate to form a paste. Each test sample weighed 3 grams when dry and 3.5 grams after 5 drops of vehicle were added. The paste material was then applied to the candle specimen with a laboratory spatula and the test specimen placed in an oven and dried at 225°F for 2 hours. The specimens having formulations prepared with silicate were found to be completely dry in 30 minutes, while those prepared with glycerine required 2 hours.

After drying, each specimen was mounted in a ring stand clamp in the laboratory hood. Specimens to be tested at soak temperatures other than ambient were conditioned to the selected test temperature. The friction surface was a flintboard, the striking material commonly used for matches.

We did not consider it necessary to burn the candle specimens to extinguishment during the tests. We considered a test successful if there was clear-cut evidence that the candle had ignited from the combustion of the material.

The results of testing each formulation are outlined below. (The formulation of each material is given in Table I).

Material 1 - Formulation failed to ignite; sparked on contact; aluminum percentage reduced for next test. (Failure)

Material 2 - Formulation failed to ignite; aluminum percentage reduced for next test. (Failure)

Material 3 - Formulation failed to ignite; aluminum percentage reduced for next test. (Failure)

Material 4 - Sodium chlorate percentage increased for this test, no ignition, sparks on contact. (Failure)

Material 5 - Formulation failed to ignite. (Failure)

Material 6 - Formulation ignited but extinguished immediately. (Failure)

Material 7 - Formulation ignited briefly but failed to ignite candle. (Failure)

Material 8 - Sodium chlorate percentage decreased for this test. (Failure)

Material 9 - Formulation failed to ignite. (Failure)

Material 10 - Formulation ignited; candle ignited but extinguished after one minute. (Partial success)

Material 11 - Formulation flared up on ignition, subsequently extinguished. (Failure)

Material 12 - Formulation failed to ignite. (Failure)

Material 13 - Formulation ignited, flared up, yielding sparks. (Partial success)

Material 14 - Formulation failed to ignite. (Failure)

Material 15 - Formulation ignited, flared up but ignited candle. Candle burned three minutes. (Partial success)

Material 16 - Formulation ignited during oven drying, no data. (Failure)

Material 17 - Formulation failed to ignite. (Failure)

Material 18 - Formulation failed to ignite. (Failure)

Material 19 - Formulation failed to ignite, sparks plentiful on contact. (Failure)

Material 20 - Formulation failed to ignite. (Failure)

Material 21 - Formulation failed to ignite. (Failure)

Material 22 - Formulation failed to ignite. (Failure)

Material 23 - Formulation ignited, candle ignited and burned for six minutes. (Partial success)

Material 24 - Formulation failed to ignite, lacked potassium nitrate. (Failure)

Material 25 - Formulation ignited, candle ignited and burned for seven minutes. (Success)

Material 26 - Formulation ignited, candle burned satisfactorily. (Success)

Material 27 - Formulation and candle ignited successfully. (Success)

Material 28 - Formulation failed to ignite. (Failure)

Material 29 - Formulation failed to ignite. (Failure)

Material 30 - Formulation failed to ignite. (Failure)

Material 31 - Formulation ignited, burned very rapidly, candle ignited. (Success)

Material 32 - Formulation and candle ignited satisfactorily. (Success)

Material 33 - Formulation failed to ignite; lacked manganese dioxide. (Failure)

Material 34 - Formulation and candle ignited; burned very rapidly. (Failure)

Material 35 - Formulation ignited, smoothest burning pattern tested. (Repeat tests with this formulation failed)

Material 36 - Formulation partially ignited before extinguishment. (Failure)

Material 37 - Formulation failed to ignite, lacked iron powder. (Failure)

Material 38 - Formulation ignited and burned rapidly, candle ignited. (Success)

Material 39 - Formulation ignited, "flare type" burning.

Material 40 - Formulation and candle ignited satisfactorily.

Material 41 - Formulation and candle ignited with smooth transition in burning.

Material 42 - Formulation and candle ignited smoothly.

Material 43 - Formulation and candle ignited smoothly.

Material 44 - Formulation flared up on ignition, burned very rapidly. (Success)

Material 45 - Formulation ignited and burned rapidly. (Success)

Material 46 - Formulation ignited, yielding sparks during burning. (Success)

Material 47 - Formulation ignited. (Success)

Material 48 - Formulation ignited, sparks persist. (Partial success)

Material 49 - Formulation ignited (increase aluminum percentage in next test, check spark tendency). (Partial success)

Material 50 - Formulation ignited, burned rapidly yielding heavy sparks. (Partial success)

Material 51 - Sodium chlorate percentage increased, formulation ignited satisfactorily. (Success)

Material 52 through Material 60 - Formulations ignited, smooth transition burning to candles. (Success)

Summarizing the test results, we had success with formulas using the following ingredients in indicated quantitative percentages and using glycerine in the preparation of ignition materials:

$NaClO_3$	85% - 88%
KNO_3	1% - 3%
$KMnO_4$	1% - 3%
Fe	2% - 5%
MnO_2	2% - 5%

These formulations ignited satisfactorily at 20°F, 70°F, and 120°F. Success was achieved more often when the sodium chlorate percentage was held at 88%. A manganese dioxide percentage of 5% assures even burning. A minimum of 4% iron powder is recommended to sustain burning. Amounts of potassium nitrate and potassium permanganate can be varied from 1% to

3%. The single exception of a formulation with 5% potassium nitrate, Material 35, was not successful in repeated tests.

SECTION IV

CONCLUSIONS

The ignition layer formulations that ignited successfully during this test program contained sodium chlorate, potassium nitrate, potassium permanganate, iron powder (reduced), and manganese dioxide, and used glycerine as the vehicle. The tests clearly established that a satisfactory ignition material would result when the percentage of each of these ingredients was varied as long as the compound contained at least 88% sodium chlorate. Using sodium silicate (water-glass solution) as the vehicle served to inhibit combustion of the ignition layer; in no instance did materials containing sodium silicate ignite, although the same materials containing glycerine readily ignited.

The results of this effort can be applied to several possible future areas of investigation. The effect of friction ignition on sodium chlorate candles of different formulation might be explored. Sodium chlorate candles which contain varying amounts of manganese dioxide could be tested to determine how the ratio of amounts of MnO_2 in the ignition layer and the candle affects the overall performance of the unit. Lithium perchlorate candles (which contain more oxygen than sodium chlorate candles) could be prepared with friction ignition layers and tested for performance, particularly ignitability at low temperatures. The combination of greater oxygen production and reliable ignition with low heat release would enhance the system applicability of chlorate candles.

Although not obvious as a conclusion of this investigation, the mechanism for activating the ignition layer (the friction device) must certainly be developed to system hardware standards. For example, it would be desirable if the friction mechanism could be contained next to the candle in a completely sealed unit and then activated externally. In any event, efforts to improve the friction device would be part of an overall program to develop a solid chemical oxygen generation system utilizing the friction ignition principle.

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